The Effects of Precipitation Assimilation on the North American Regional Reanalysis Water Cycle

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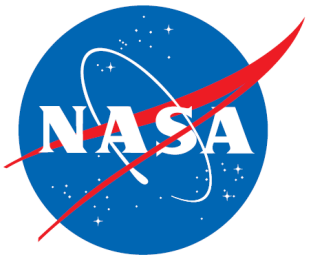

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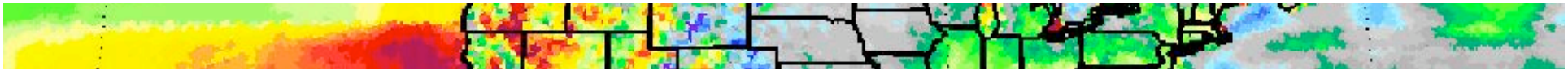

Overview

1. Impacts Research at GISS
   - Bangladesh
   - RCM over Central America
2. North American Regional Reanalysis Water Cycle
3. Mean balance
4. Precipitation Assimilation
5. Normalized Covariance Approach
6. Annual Component Interactions
7. Diurnal Component Interactions

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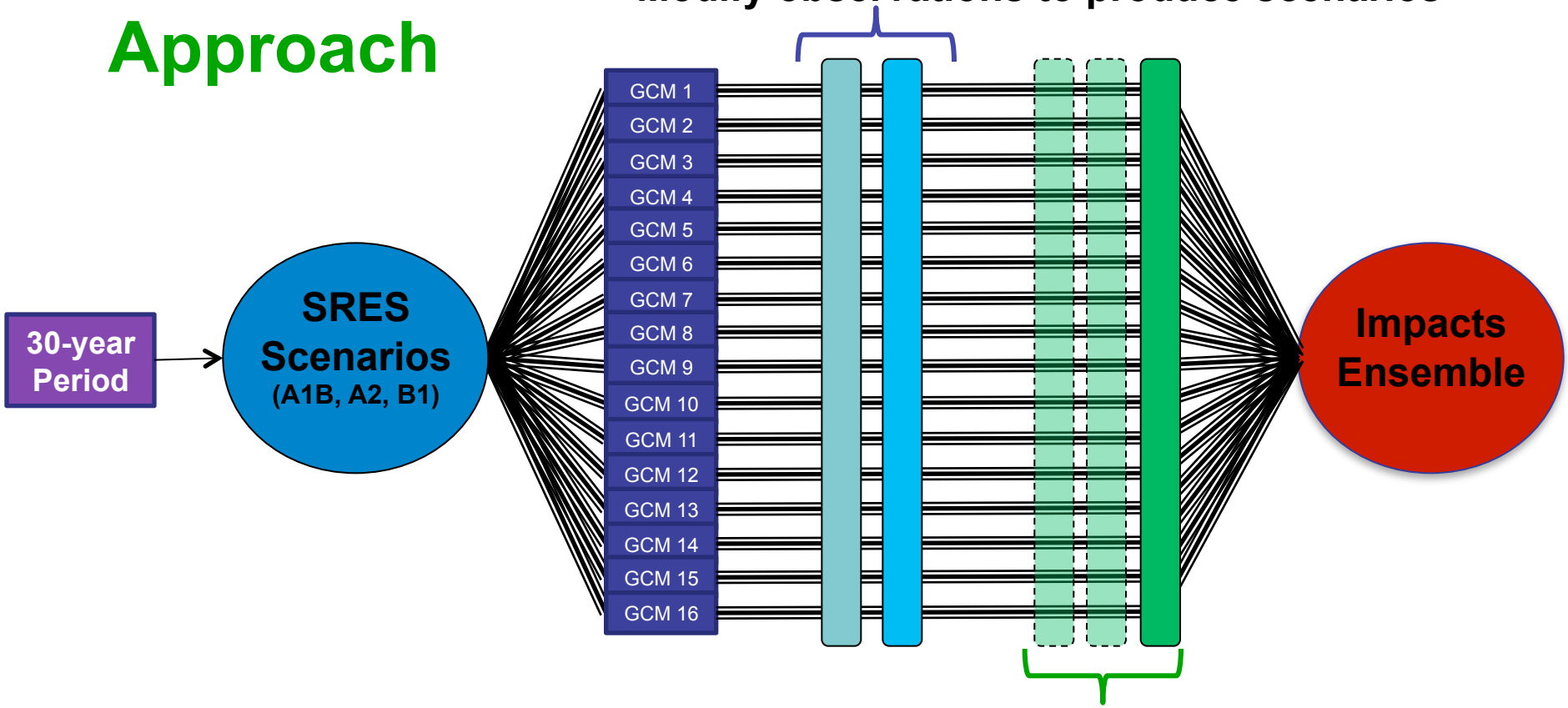
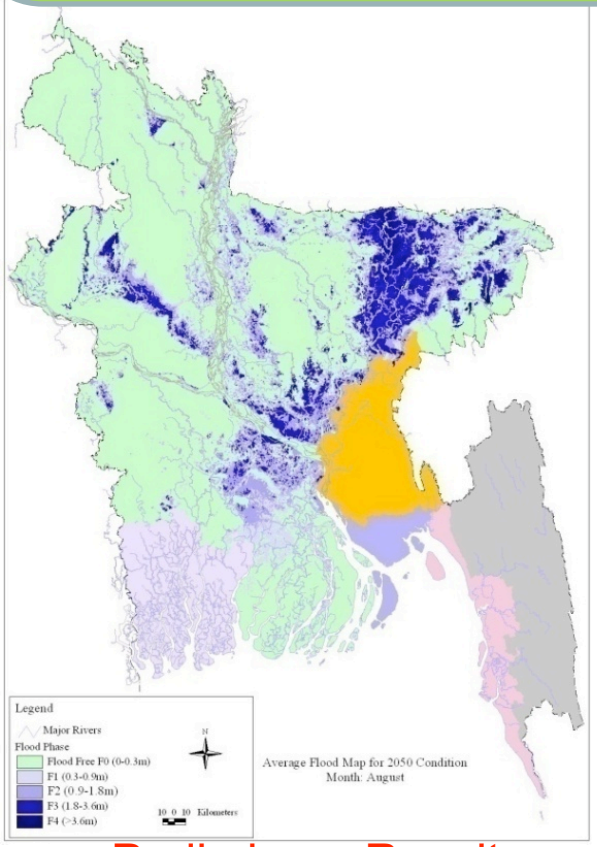
Integrated Climate Impacts Approach

Climate Scenarios:
Calculate climate changes relative to baseline
Downscale if necessary
Modify observations to produce scenarios



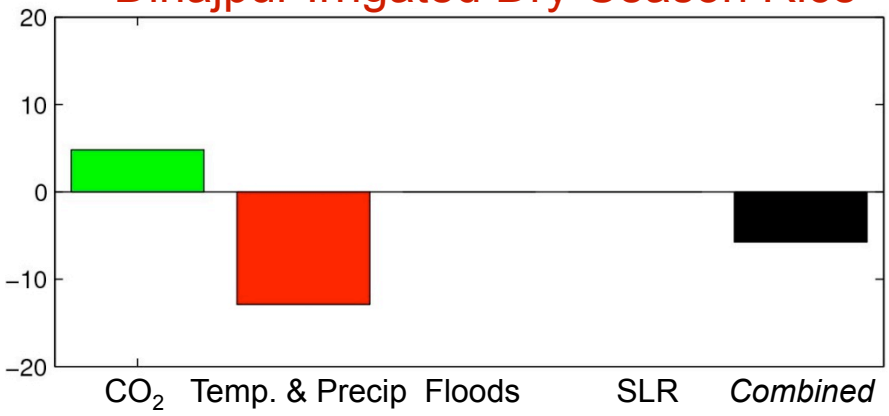
Impacts Assessment Models:
Pass each scenario all the way through process
Only produce ensemble at end
Crop, hydrologic, and coastal models for Bangladesh

% Change in Potential Rice Yield for Each Impact Component (Bangladesh)



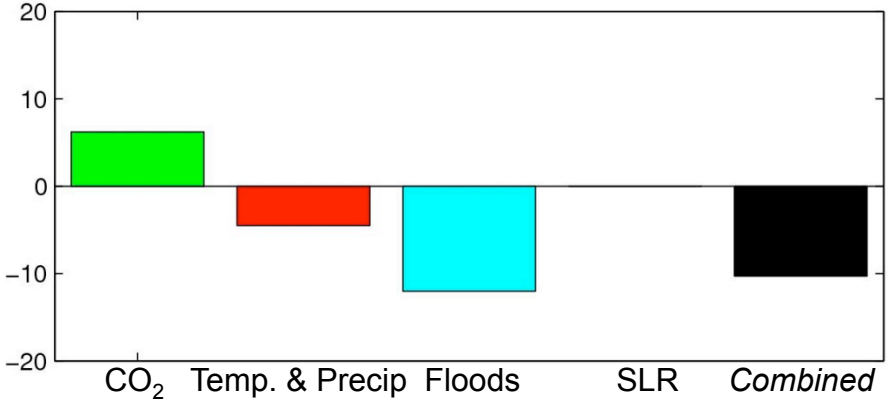
<Preliminary Results>
(median displayed)

Dinajpur Irrigated Dry-Season Rice



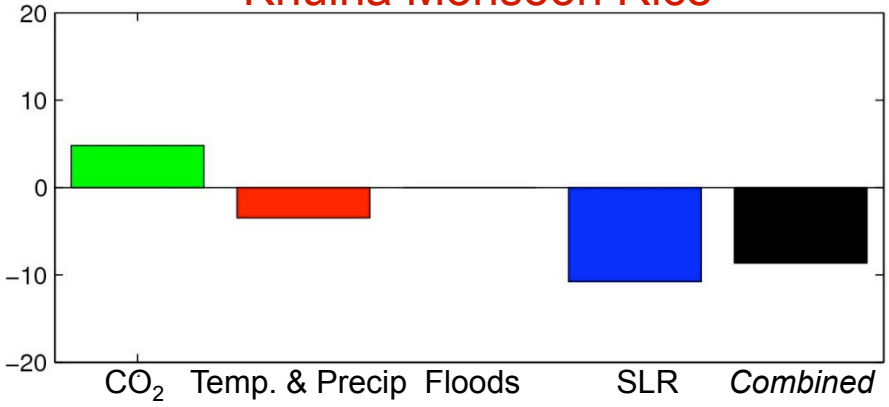
Drought Region example

Ishwardi Monsoon Rice



Flood Region example

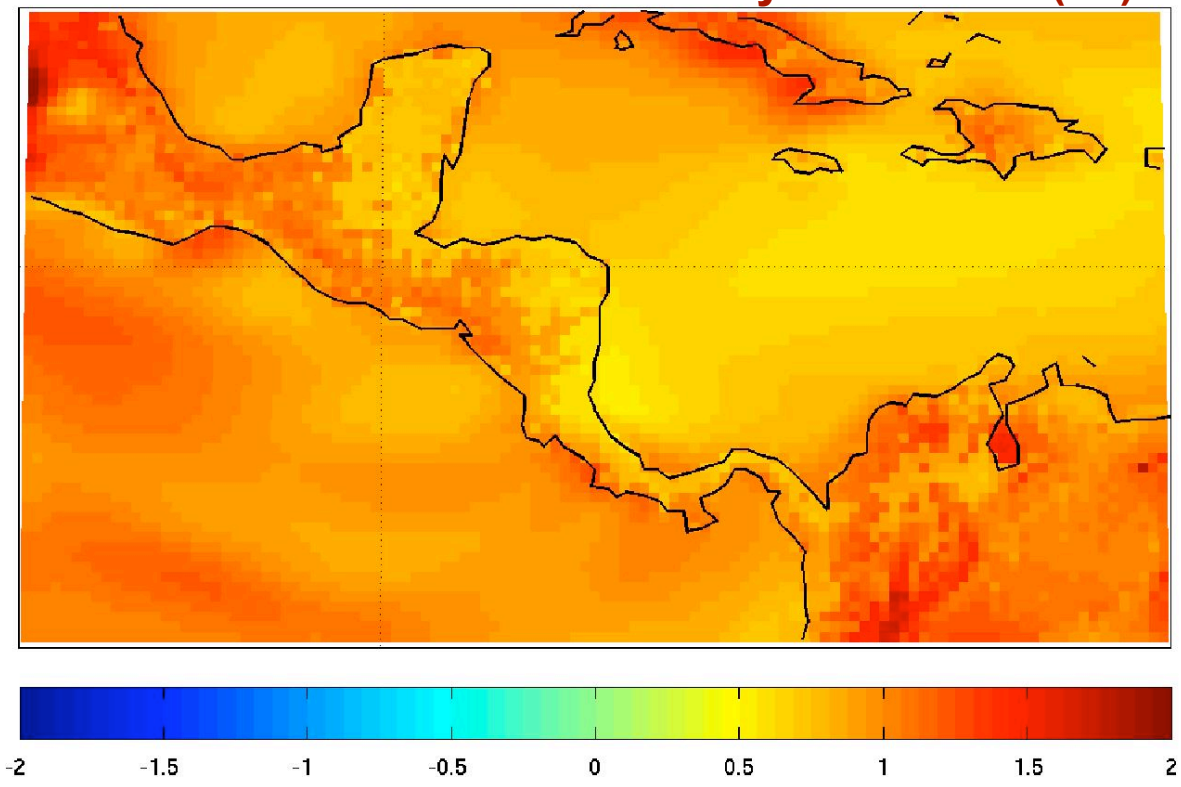
Khulna Monsoon Rice



Coastal Region example

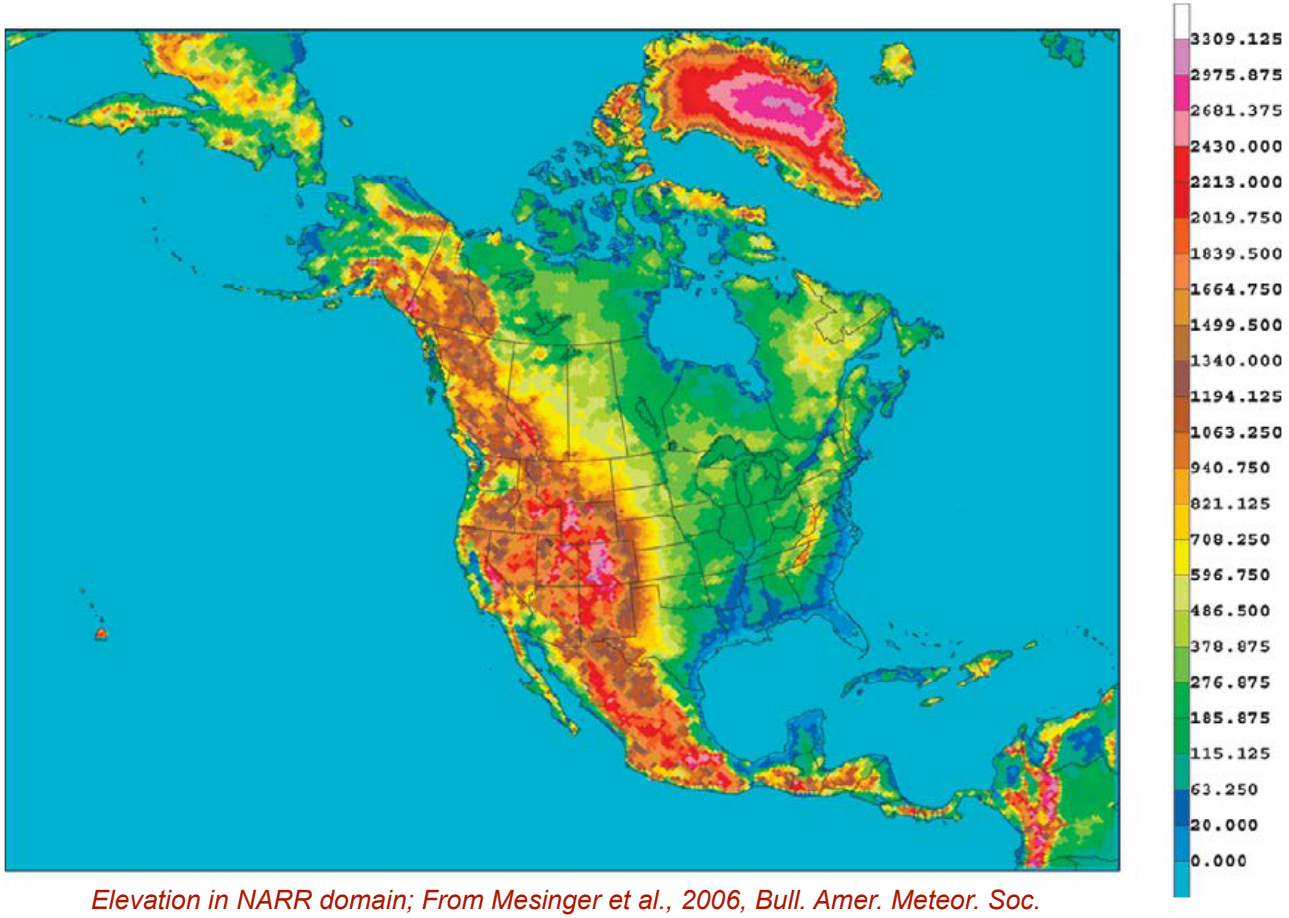
CCSM/WRF Regional Climate Simulations

2020-2040 A2 scenario July Temperature minus 1970-1990 20th Century simulation (°C)



- **Large changes across short distances that could not be captured in the coarser CCSM.**
- **Mountains warm faster than surrounding lowlands.**
- **Project designed for impacts analysis**
  - **2020-2050 A2 and B1 simulations**
  - **Compared to 1970-2000 baseline and 1980-2000 Reanalysis-2**

NARR Overview



Elevation in NARR domain; From Mesinger et al., 2006, Bull. Amer. Meteor. Soc.

The NCEP North American Regional Reanalysis (NARR) covers 1979-2003 at 32-km and 3-hourly resolution.

- Driven by NCEP/DOE Reanalysis-2 forcing conditions

- Assimilates state variables every 3 hours

- Precipitation and radiance assimilation every hour

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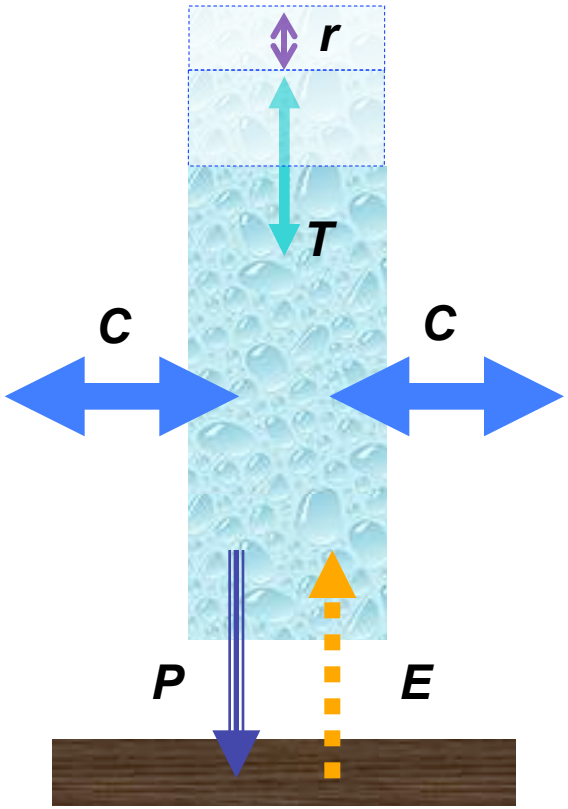
The Atmospheric Water Budget



$$\frac{\partial\{q\}}{\partial t} = -\nabla \cdot \{vq\} + E - P + r$$

Precipitable Water Tendency =

Moisture Flux Convergence + Evaporation – Precipitation + residual

$$(\overline{T} + T') = (\overline{C} + C') + (\overline{E} + E') - (\overline{P} + P') + (\overline{r} + r')$$

Mean balance: $\overline{T} = \overline{C} + \overline{E} - \overline{P} + \overline{r}$

Transient balance: $T' = C' + E' - P' + r'$

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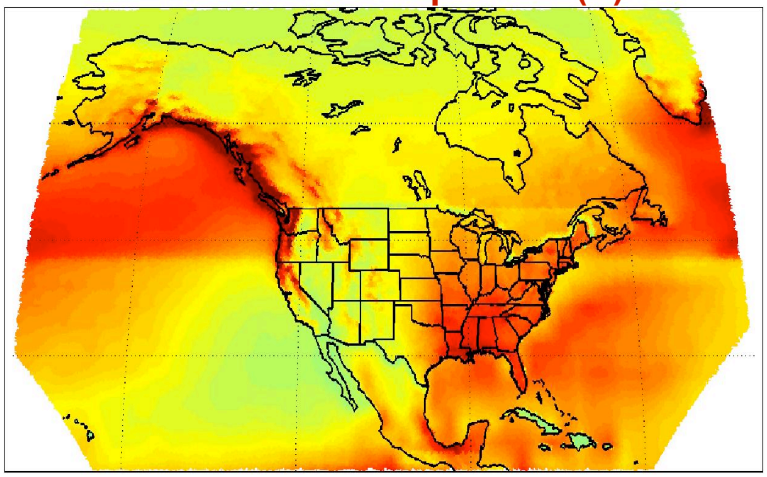
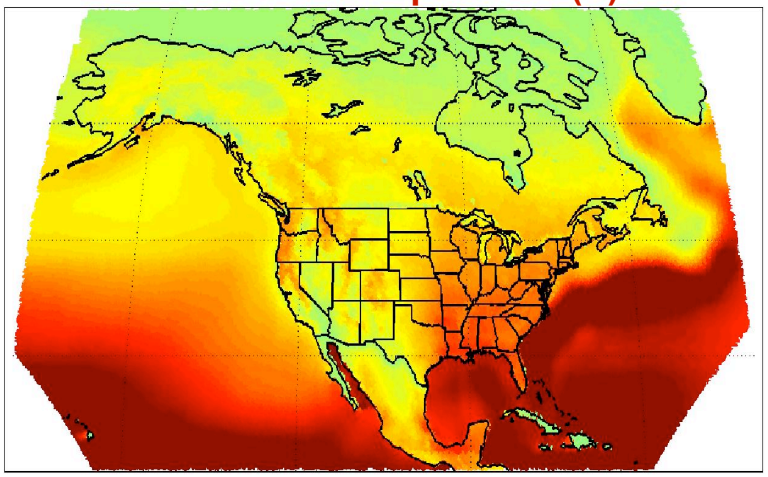
Mean Balance (mm/d)

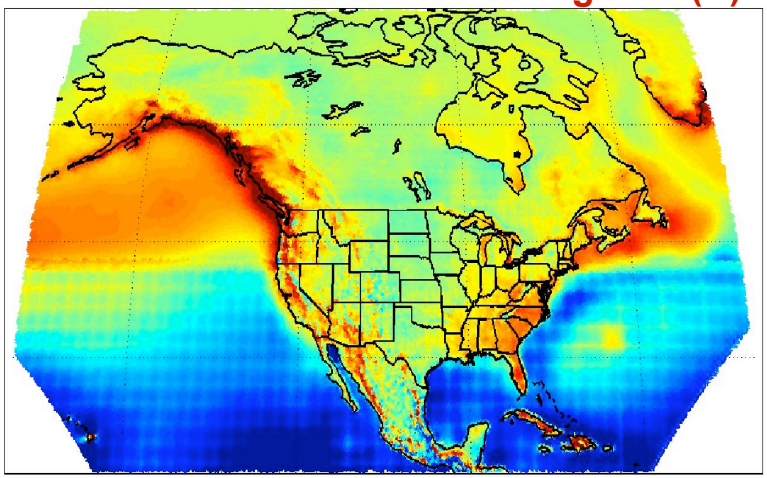
1980-1999 Precipitation (*P*)



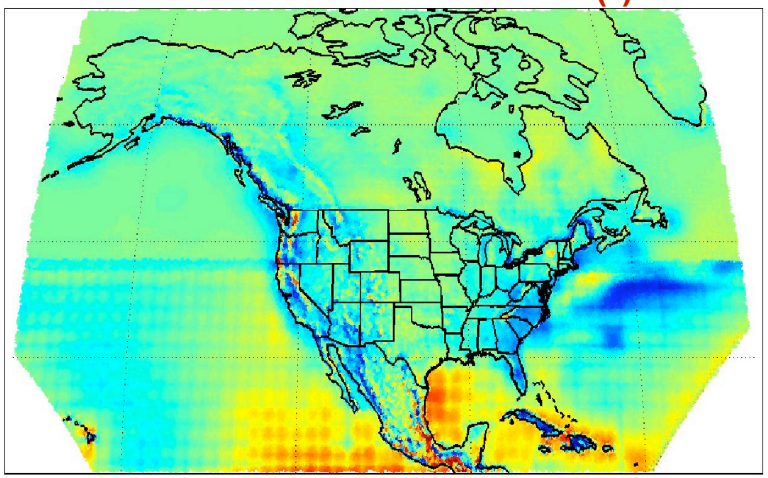
1980-1999 Evaporation (*E*)



1980-1999 Moisture Flux Convergence (*C*)



1980-1999 Residual Term (*r*)



Note that the tendency term is negligible (<0.2mm/d) over the 20-year period

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Sources of Assimilated Precipitation

Region	Assimilation Source	Frequency of Source Measurements	Higher Frequency Filling
Continental United States	1/8° rain gauge analysis with PRISM	Daily	2.5° hourly analysis
Canada	1° rain gauge analysis	Daily	~1.9° Reanalysis-2 hourly weights
Mexico	1° rain gauge analysis	Daily	~1.9° Reanalysis-2 hourly weights
Land South of Mexico	2.5° CMAP precipitation analysis	Pentad	~1.9° Reanalysis-2 hourly weights
Alaska	None	None	None
Oceans, south of 27.5° latitude	2.5° CMAP precipitation analysis	Pentad	~1.9° Reanalysis-2 hourly weights
Oceans, 27.5°-42.5°	2.5° CMAP precipitation analysis to South blended with no assimilation to North	Pentad	~1.9° Reanalysis-2 hourly weights
Oceans, north of 42.5° latitude	None	None	None

CMAP = CPC Merged Analysis of Precipitation

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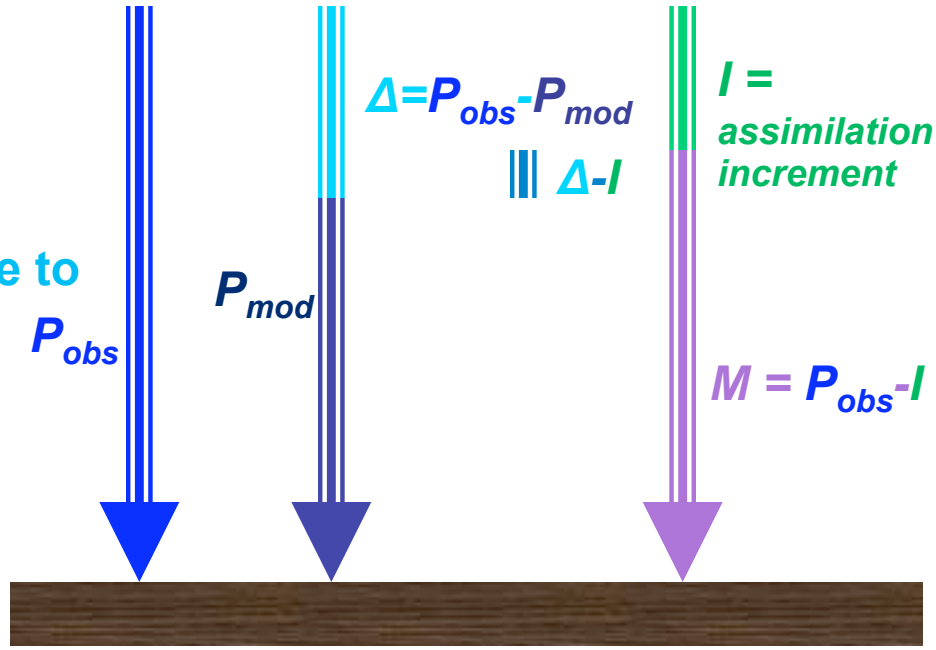
Precipitation Assimilation

Precipitation assimilation accomplished by comparing model-generated precipitation to observed precipitation analyses and adjusting using a moisture increment (hourly)

- -If Δ >0: Revise convective parameters to drive appropriate amount of additional convection
- -If Δ<0: Adjust latent heating profile to slow convection
- -Liquid water and water vapor increments added to precipitable water column to reduce strain on convective parameterization
  - ➢Add water into column if too dry
  - ➢Remove water if too wet
  - ➢No adjustment of evaporation or moisture flux convergence
- -Useful to define model precipitation estimate (M)



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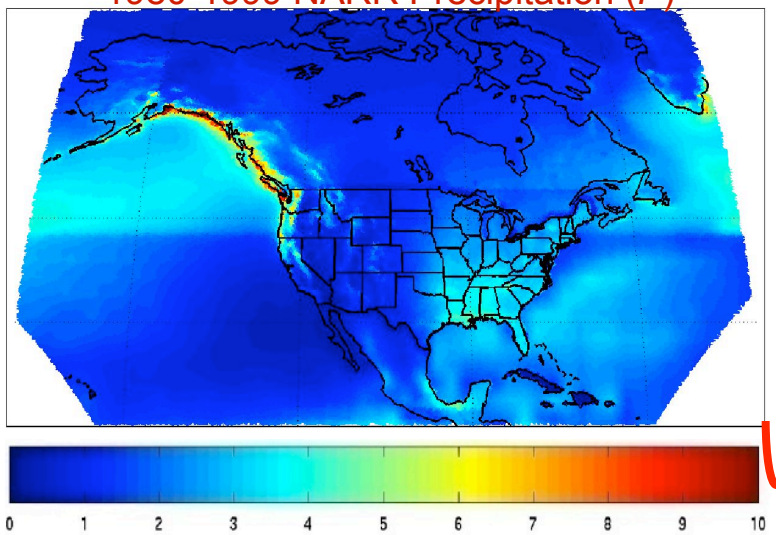
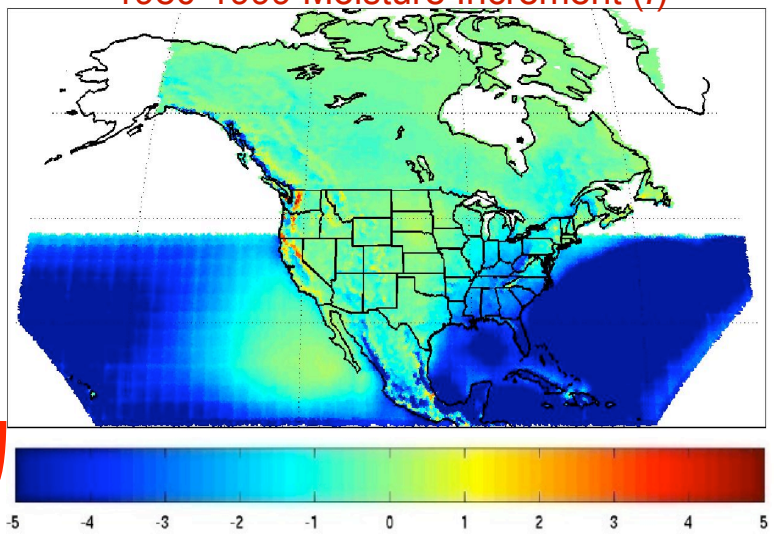
Model Precipitation Estimate

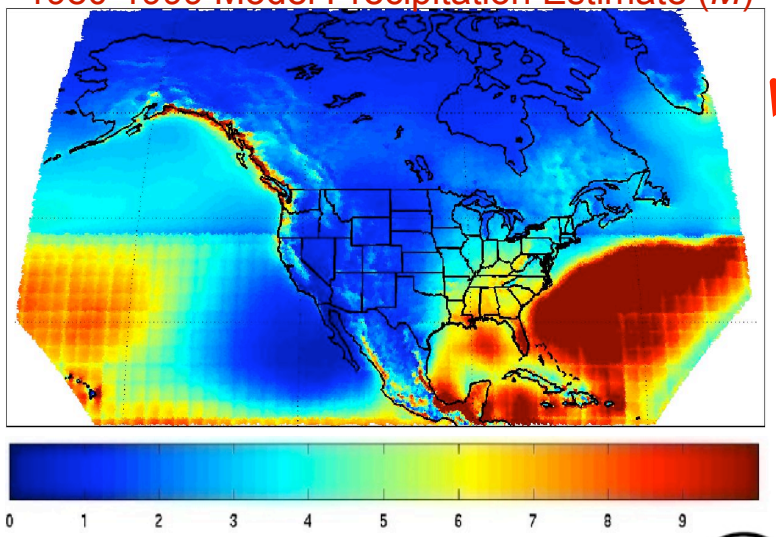
1980-1999 NARR Precipitation (*P*)



1980-1999 Moisture Increment (*I*)



1980-1999 Model Precipitation Estimate (*M*)



$$M \overset{\text{def}}{=} P - I$$

More active hydrologic cycle suggested in underlying model

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Normalized Covariance

Transient balance: $P' = C' + E' - T' + r'$

Isolated diurnal and annual variation using band-pass Fourier filtering

1) Take covariance of each side with *P'*
2) Divide by variance of *P'*
3) Multiply by 100%:

Normalized covariance equation, see Ruane and Roads (2008a,b):

$$\frac{cov(P',P')}{var(P')} * 100\% = \frac{cov(C',P') + cov(E',P') + cov(-T',P') + cov(r',P')}{var(P')} * 100\% = 100\%$$

"Normalized covariance" of *Q'* with *P'* = cov(*Q'*,*P'*)/var(*P'*)

- sum of budget normalized covariances explain 100% of a variable's variance

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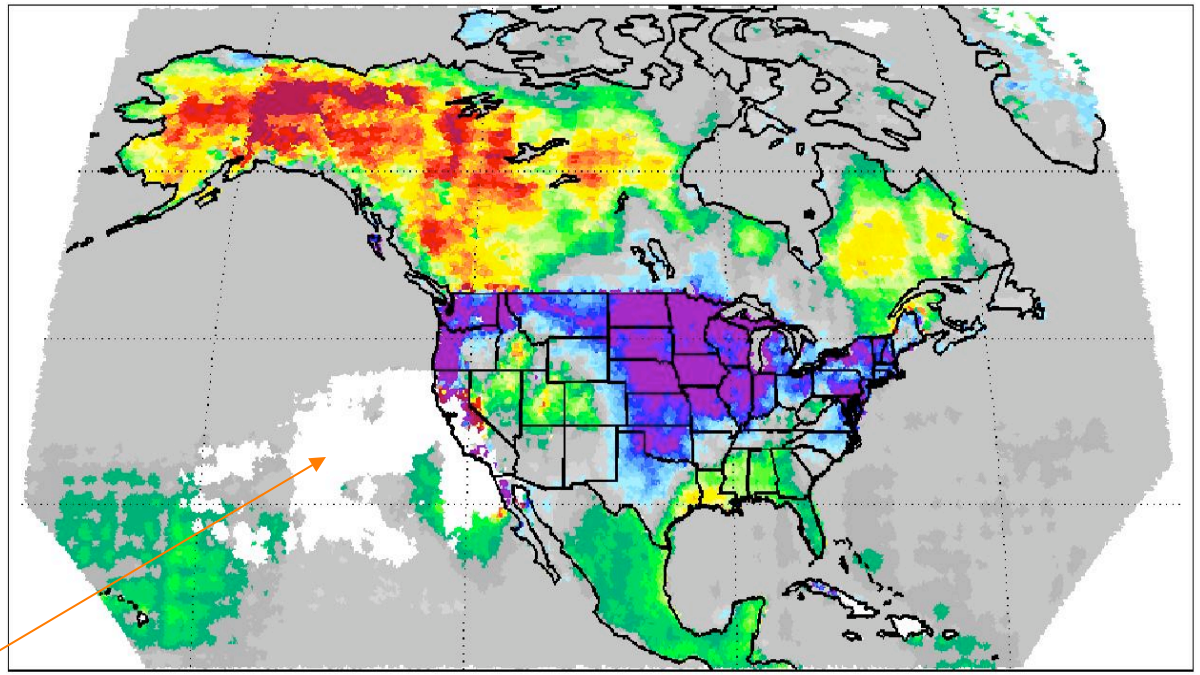
Visualization Example

Normalized Covariance of Evaporation with Precipitation in the Diurnal Band

$$\frac{\mathrm{cov}(E', P')}{\mathrm{var}(P')} \times 100\%$$



Insignificant areas omitted

(excludes regions with low rainfall in this case)

<0% = Normalized covariance indicates variance with opposite phase

0% = No covariant relationship

100% = Covariance explains all variance

>100% = Covariance exceeds variance

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Annual Water Cycle Interaction

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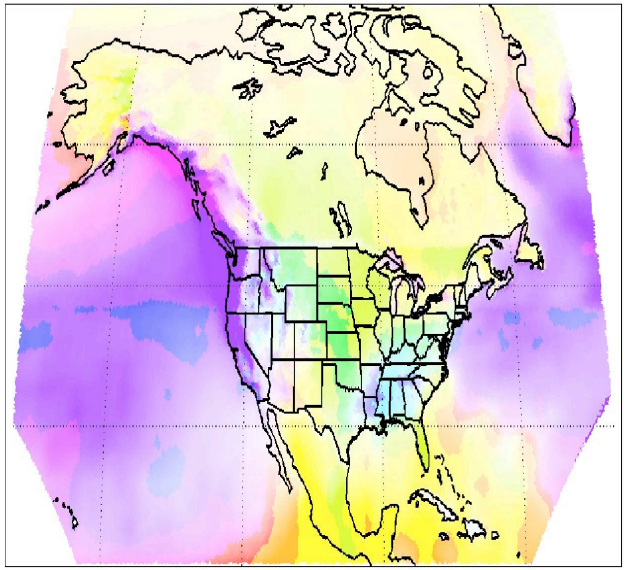
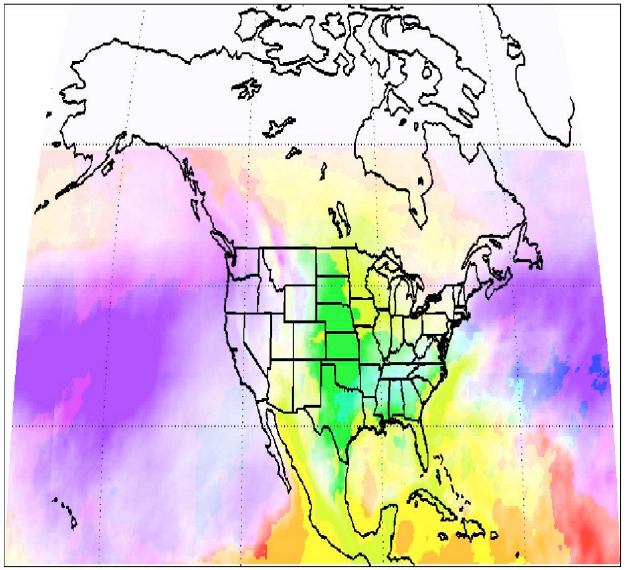
Annual Precipitation Harmonics

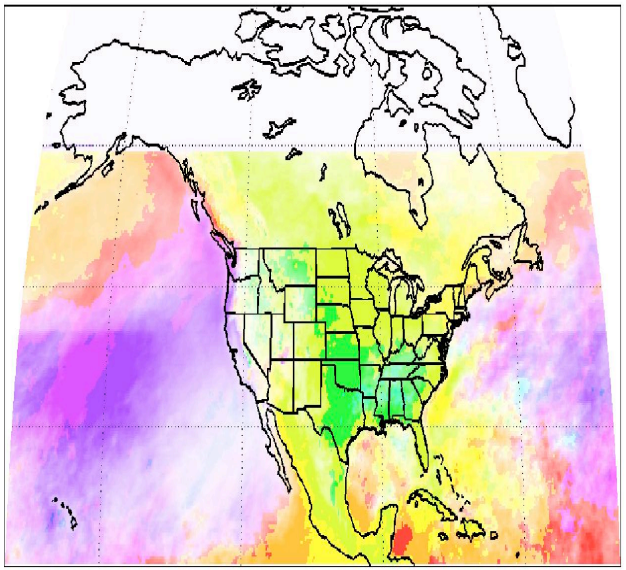
1980-2000 NARR



2003-2007 PERSIANN



2003-2007 CMORPH



Annual cycle has regional differences

- Wintertime over West
- Early summer over continental interior
- Low magnitude over SE USA

NARR closer to PERSIANN than CMORPH

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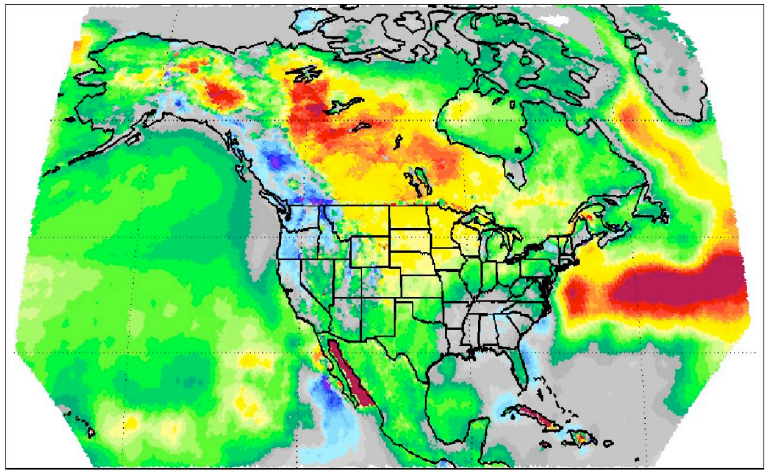
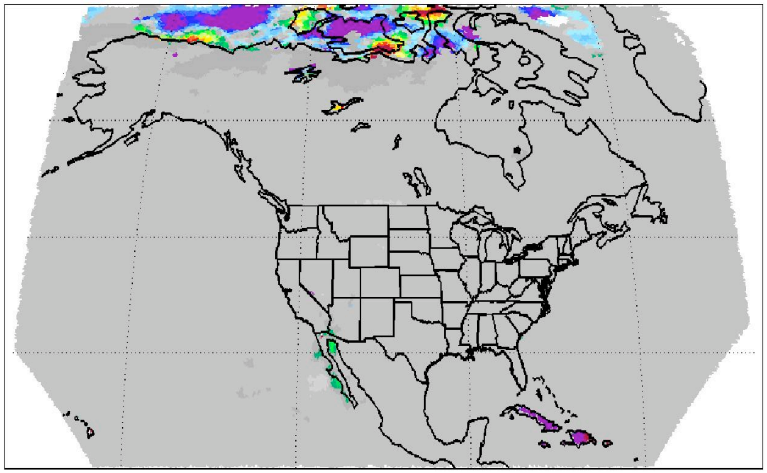
Annual Precipitation Band

cov(E',P')/var(P')

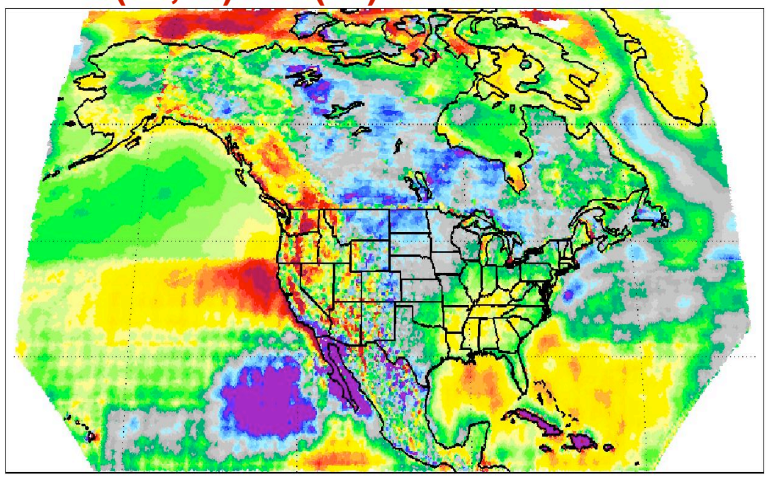


Sum of all four = 100% for every grid point

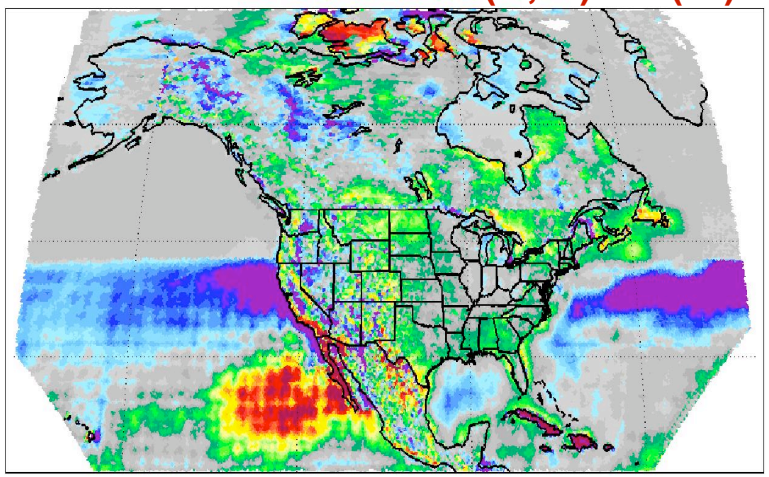
cov(-T',P')/var(P')



cov(C',P')/var(P')



cov(r',P')/var(P')



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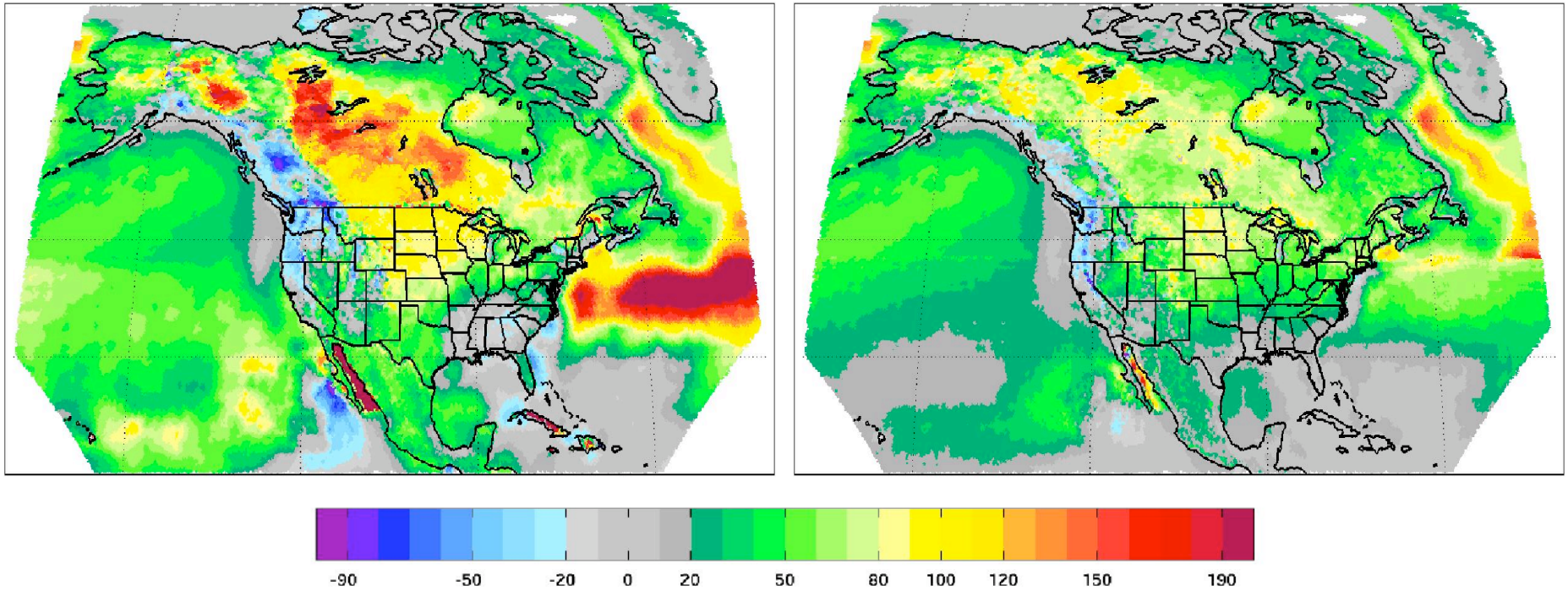
Annual Budget Errors

cov(E',P')/var(P')

cov(E',M')/var(M')



Covariances of Evaporation with Precipitation and Model Precipitation Estimate

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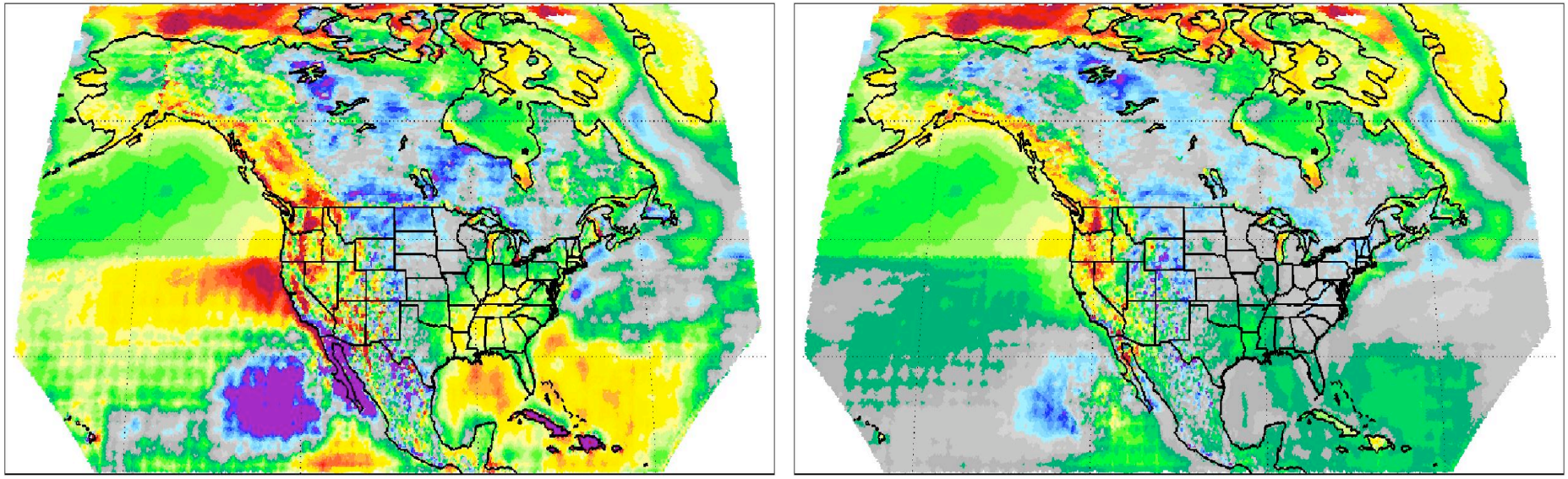
Annual Budget Errors

cov(C',P')/var(P')

cov(C',M')/var(M')



Covariances of Moisture Flux Convergence with Precipitation and Model Precipitation Estimate

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Diurnal Water Cycle Interaction

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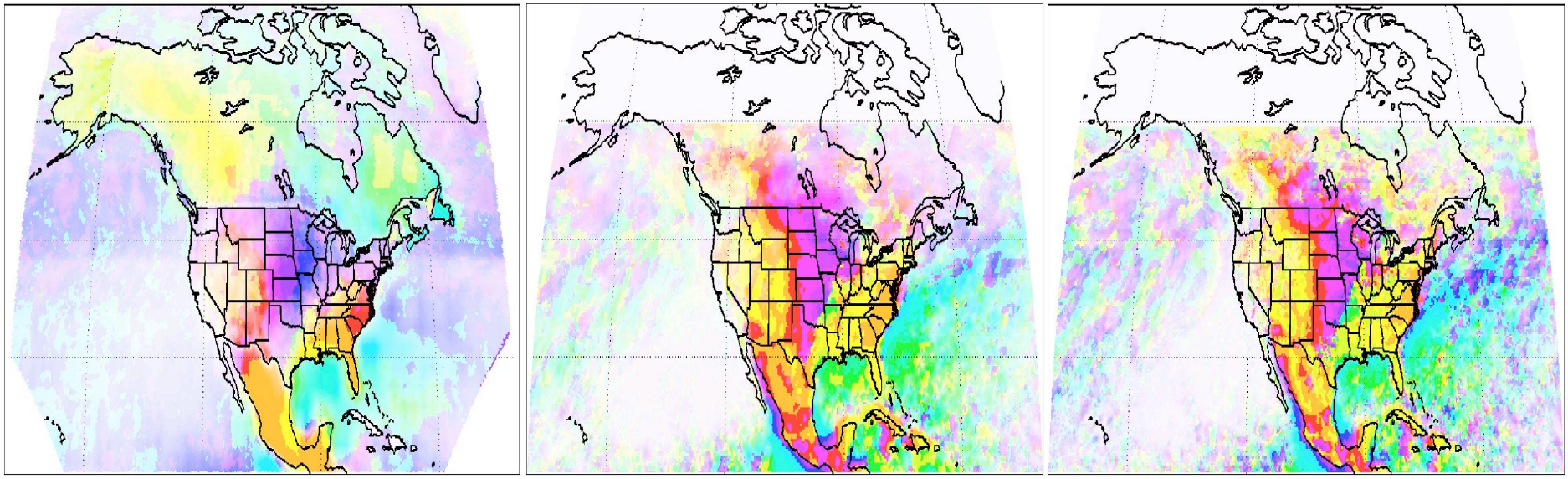
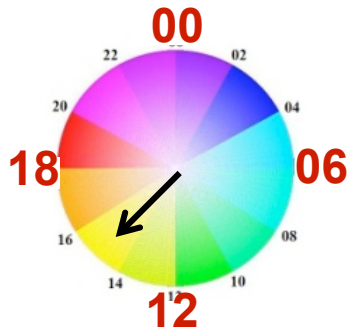
Summertime Diurnal Precipitation Harmonics

1980-2000 NARR | 2003-2007 PERSIANN | 2003-2007 CMORPH





Diurnal cycle has large variation across North America

- Nocturnal maximum over Upper Midwest
- NARR does not match satellite-based High-Resolution Precipitation Products

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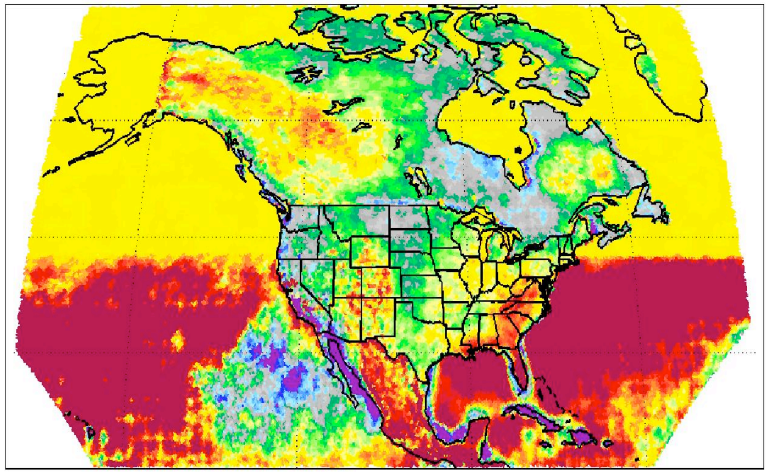
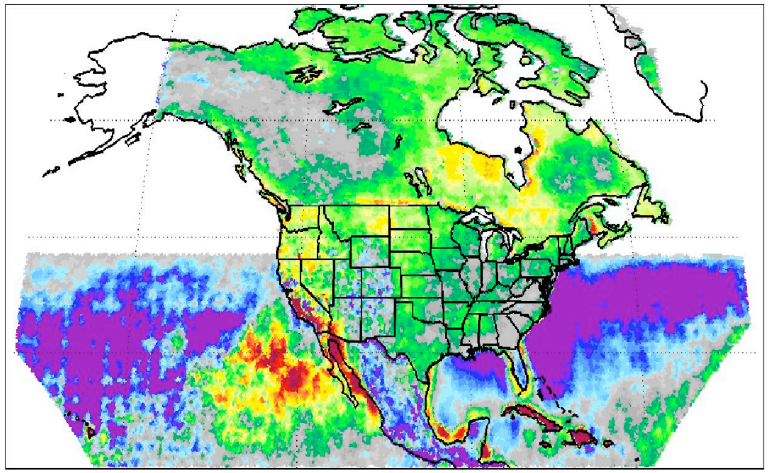
Summertime Diurnal Band of Precipitation Assimilation

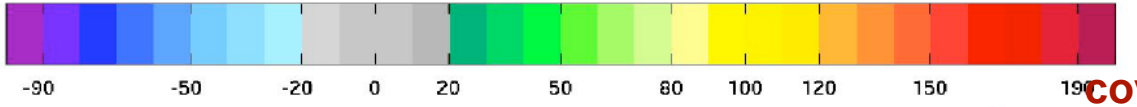
cov(M',P')/var(P')



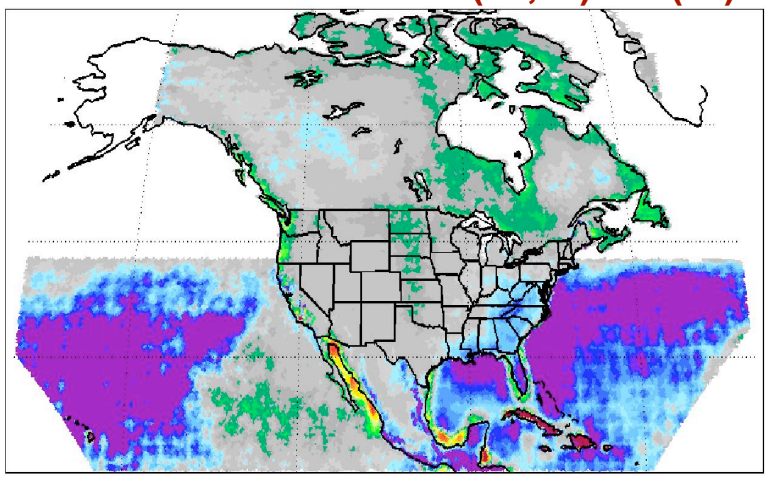
Sum of all three = 100% for every grid point

cov(V',P')/var(P')





cov(D',P')/var(P')



$$I' = V' + D'$$

$$\Rightarrow P' = M' + V' + D'$$

The precipitation assimilation Increment consists of both a Vapor and clouD condensate term which may be analyzed separately

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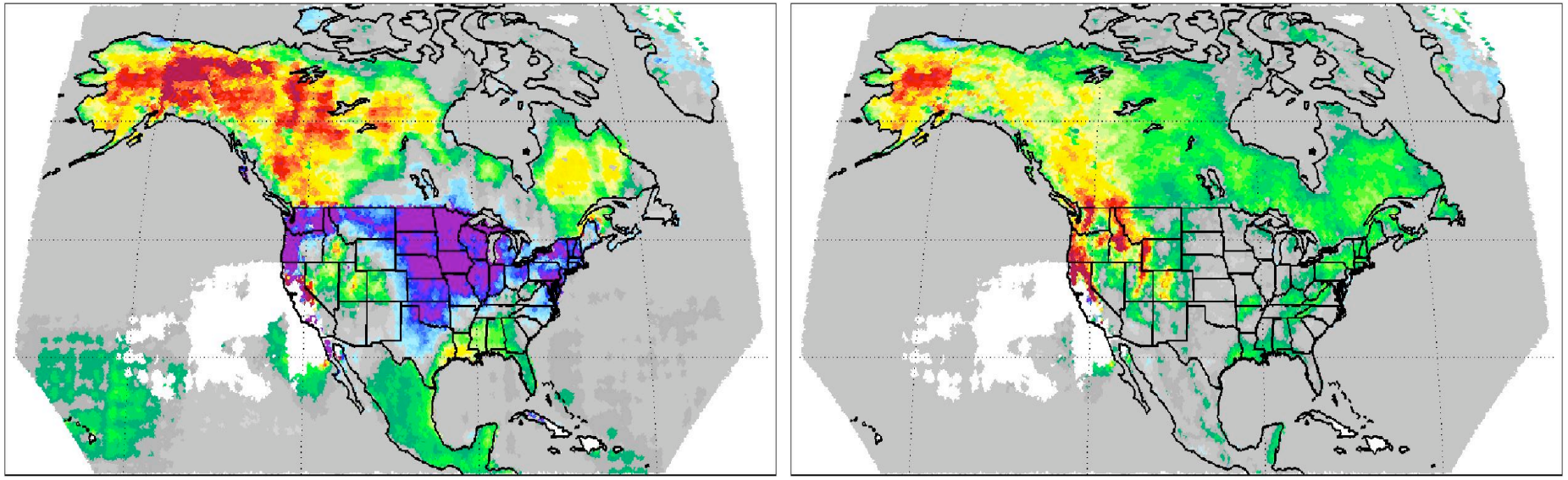
Diurnal Budget Errors

cov(E',P')/var(P')

cov(E',M')/var(M')



Covariances of Evaporation with Precipitation and Model Precipitation Estimate

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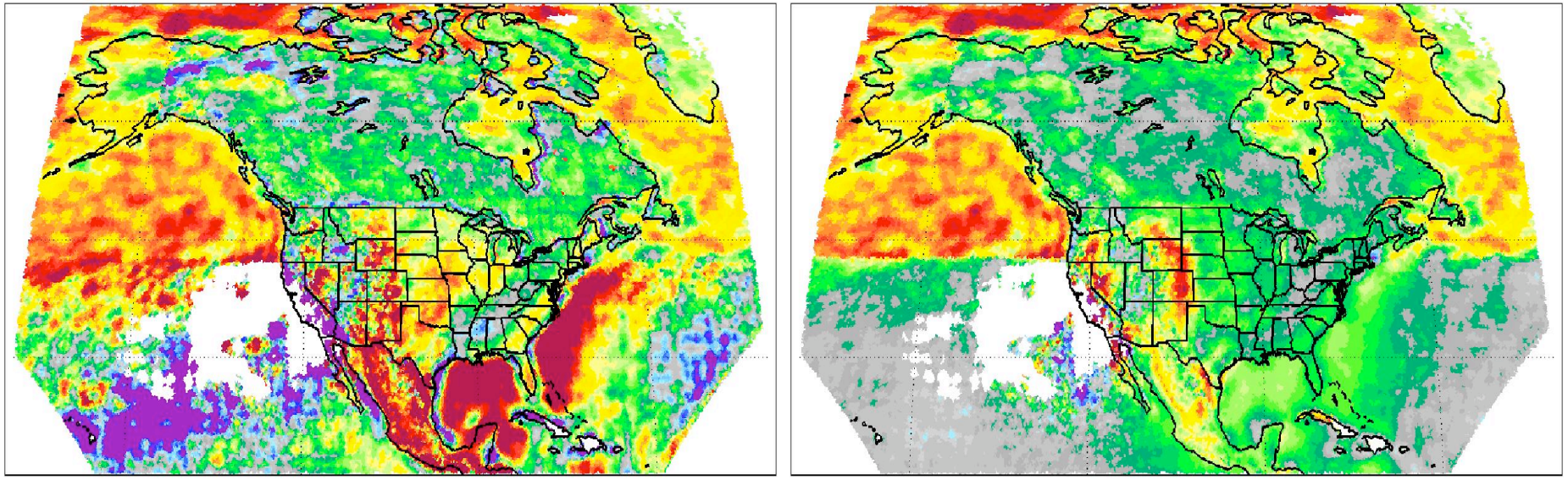
Diurnal Budget Errors

cov(C',P')/var(P')

cov(C',M')/var(M')



Covariances of Moisture Flux Convergence with Precipitation and Model Precipitation Estimate

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Summary

- **Precipitation assimilation requires new considerations in atmospheric water budget analysis**
  - **Regional precipitation input may affect impact assessments**
- **NARR output overestimates the role of other atmospheric water cycle components that are not directly adjusted by precipitation assimilation**
- **Normalized covariance statistic reveals interesting regional balances and exchanges**
  - **Nocturnal maximum over upper US Midwest: Precipitation assimilation reduces daily summer rainfall and adds a lesser amount during summer nights**
- **Background and future publications**
  - **Normalized covariances for Reanalysis-2 in Ruane and Roads, 2008a (*J. Climate*)**
  - **Sensitivity comparisons in Ruane and Roads, 2008b (*Earth Interactions*)**
  - **The NARR results presented here will be submitted as annual and diurnal companion papers (Ruane, 2009a,b, *in preparation*)**
  - **Normalized covariance anomalies used to examine 1993 flood and 1988 drought (Ruane, 2009c, *in preparation*)**

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